THE POTENTIAL IMPORTANCE OF *SPARTINA ALTERNIFLORA* IN CONVEYING ZINC, MANGANESE, AND IRON INTO ESTUARINE FOOD CHAINS

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THE POTENTIAL IMPORTANCE OF *SPARTINA ALTERNIFLORA* IN CONVEYING ZINC, MANGANESE, AND IRON INTO ESTUARINE FOOD CHAINS[1]

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Abstract. The potential importance of cord grass, *Spartina alterniflora*, in conveying radioisotopes of zinc, manganese, and iron into estuarine food chains was evaluated on the basis of its annual production, its content of the three elements, and its annual cycle of growth and decay. The growth of *Spartina* was studied with harvest and other techniques in salt marshes near Beaufort, N.C. Standing crop at maturity (in the fall) and annual production were estimated to average 545 and 650 g dry wt/m^2, or 208 and 248 g C/m^2, respectively. *Spartina* production approached one-third the total phytoplankton net production of adjacent estuaries, and was thus potentially important in estuarine food chains. Zinc, manganese, and iron all had markedly higher concentrations in dead *Spartina* than in live, and averaged 22, 200, and 5000 ppm (dry wt), respectively, in the dead material. The unusually high iron content of the dead material suggested that *Spartina* detritus may be especially important in the movement of radioisotopes of iron from water and sediment into estuarine animal populations.

Introduction

Aquatic animals may obtain radionuclides either directly from the water in which they live or from food and other materials that they eat. In many inshore areas, salt marshes of cord grass, *Spartina alterniflora* Loisel, form an important source of food for animal populations in adjoining waters. Thus *Spartina* may act as a vehicle transporting radionuclides from water and sediment to animal populations. Since June 1965 we have investigated the potential importance of this transport mechanism for zinc, manganese, and iron in a system of shallow estuaries on the coast of North Carolina (Fig. 1). We conducted this study to increase our insight into the flow of energy and materials in an estuarine ecosystem, and to evaluate the need for more detailed studies on the actual role of *Spartina* in the cycling of radioisotopes. We concentrated our research on *Spartina* because it covers much of the normally intertidal area in pure or almost pure stands. Preliminary studies suggested that little of the organic matter produced by plants of the irregularly flooded high marshes was exported to the estuaries.

Determining the potential importance of *Spartina* in conveying radionuclides of zinc, manganese, and iron into estuarine food chains required three types of information: the annual production of *Spartina*, its content of the three elements, and the average period between the formation of new tissue and its decomposition after death. From the total annual production we estimated the importance of *Spartina* as a food source for animal life in the estuaries. The elemental composition indicated the maximum amount of zinc, manganese, and iron which might be available to animals from the grass. The period of time between growth and decomposition provided a measure of the extent of physical decay undergone by radionuclides initially incorporated in the tissues before their entrance into estuarine food chains. Most *Spartina* reaches estuarine animals either as detritus or as microorganisms nourished on detritus (Teal 1962).

The growth and distribution of *Spartina* were described by Burkholder (1956), Good (1965), Morgan (1961), Smalley (1959), Teal (1962), and others. *Spartina* is a grass with perennial rhizomes. These produce an annual crop of stalks often exceeding 2 m in height at the lower edge

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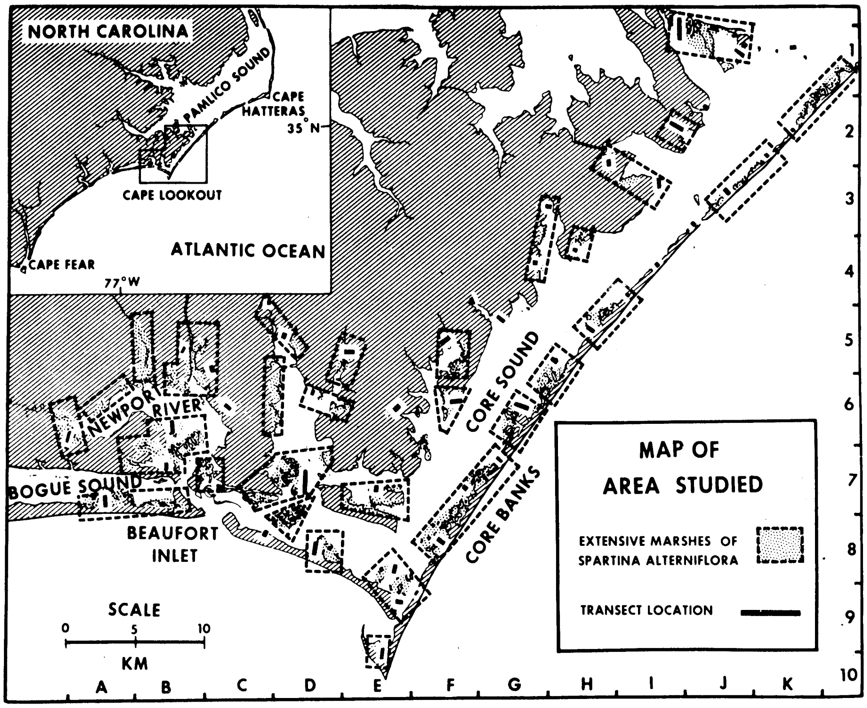

Fig. 1. Map of the area studied, showing the location of extensive *Spartina alterniflora* marshes and of the transects run through the marshes. In addition to the marsh areas shown, there are narrow fringes of *S. alterniflora* along many of the shorelines.

of the marsh, and decreasing in height with increasing elevation of the marsh. Since *Spartina* grows by lengthening its stalk and adding new uppermost leaves which eventually replace older leaves below, the standing crop at maturity is less than the season's production. The fallen leaves and dead stalks begin their decay in the marsh, but most are eventually carried out by the tides. There is no clear evidence that the organic matter of the roots and rhizomes is ever exported from the marsh.

Methods

A harvest technique was used to determine the standing crop of *Spartina* and to estimate the production prior to the moment of harvest. Stalks were cut close to the ground and all living and dead material collected from either 1 m^2 or 0.2 m^2 areas of marsh. At the laboratory, living plants were separated from debris, and both were dried and weighed. On a subsample of living plants we counted the number of dead leaves and leaf scars, and determined the average dry weight of a mature leaf. From these determinations on the subsample we calculated the amount of material, i.e., leaves, which had died prior to harvest. In addition, average height was obtained by measuring *ca.* 20 randomly selected stalks.

The carbon in *Spartina* was determined with a carbon-hydrogen-nitrogen analyzer against a standard of cyclohexanone-2,4-dinitrophenylhydrazone. Ash was weighed after combusting samples at 450 C for 16 hr. Zinc, manganese, and iron were measured with an atomic absorption spectrophotometer against standards of known concentration. To prepare *Spartina* for spectrophotometric analysis, 2.0 to 5.0 g samples of dry material were dissolved in 50 ml of concentrated nitric acid and slowly refluxed with occasional small additions of hydrogen peroxide until the digests were colorless. The acid was then evaporated and the samples were redissolved in 50 ml of 0.25 *N* HCl, and filtered through Whatman No. 42 paper to remove sand grains and other insoluble particles.

Results and Discussion

Production of Spartina *per Square Meter.* The growth of *Spartina* throughout the year was delineated by sampling at 5-week intervals from June 1965 to September 1966. The samples consisted of above ground growth from 1 m^2 of *Spartina* at each of 10 locations. The locations, all within 3 km of the Radiobiological Laboratory, were in sections B7 and C7 on Fig. 1. Most of the range of marsh elevation and grass height was sampled by these 10 locations. Results from the analysis of these samples are summarized in Fig. 2. Values before mid-September 1965 (indicated by a vertical dashed line in Fig. 2) were not strictly comparable with one another or with values after September 1965 because methods of analysis were slightly modified and sampling locations shifted about during this initial period. Starting in October 1965, values were comparable with one another.

The aboveground portion of *Spartina* was largely an annual growth; most mature stalks died in early winter (Fig. 2). Thus, one year's production was easily separated from others, and the production associated with the peak standing crop present in the fall provided an estimate of annual production. In the tall *Spartina* of the streamside marsh, development of new sprouts (which mature into next year's plants) started in early summer. Annual production of tall *Spartina* was therefore the difference between production computed at the time of the peak standing crop of mature plants, and the portion of this production consisting of new sprouts. In medium and short *Spartina*, new sprouts are not important until fall or winter. Thus, annual production of medium and short *Spartina* is the production at the time of peak standing crop.

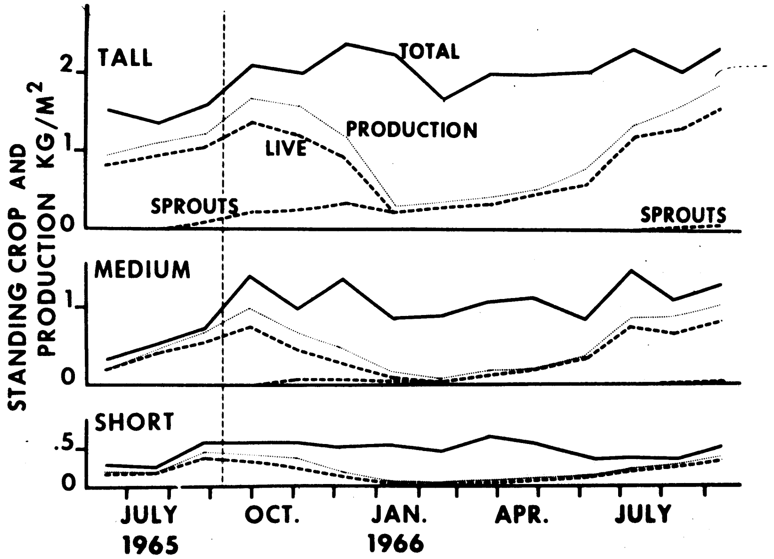

Fig. 2. Seasonal changes in the standing crop and production of *Spartina*. The dashed line indicates the standing crop of living plants. Where both new sprouts and more mature plants were present, the lower dashed line indicates the standing crop of sprouts and the upper dashed line the combined standing crop of sprouts and mature plants. The dotted line indicates total production estimated from the standing crop of living plants. The solid line indicates the combined standing crop of living and dead *Spartina*. Values to the left of the vertical dashed line are not strictly comparable with each other or with values to the right, because methods of analysis were slightly modified and sampling locations shifted about during the initial period of the study. Values to the right of the line for tall *Spartina* are averages of four 1 m^2 samples, and for medium and short *Spartina*, averages of three 1 m^2 samples. At maturity the tall *Spartina* averaged 140 cm; the medium, 80 cm; and the short, 43 cm.

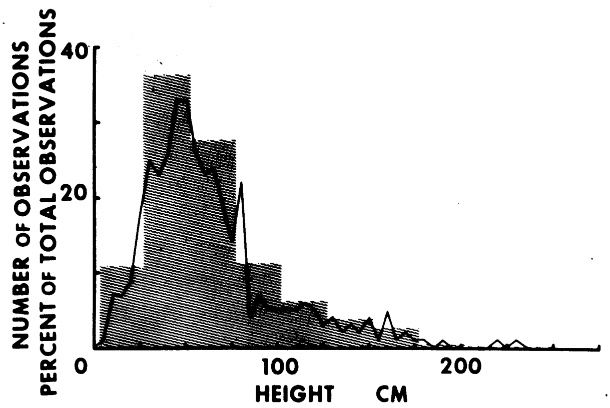

Fig. 3. Height-frequency distribution of *Spartina*. The line indicates the number of observations in each 5-cm height interval. The block diagram indicates the percentage of the total observations in 25-cm height intervals.

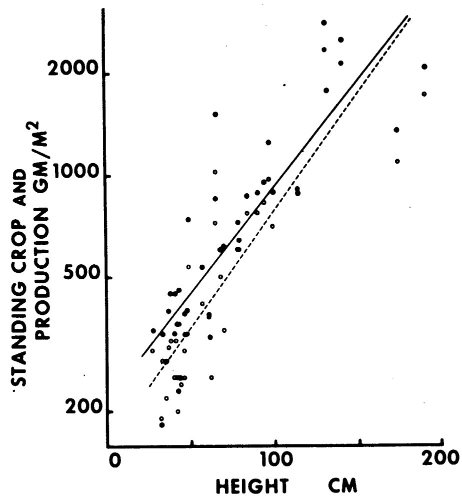

Fig. 4. Standing crop of living *Spartina* at maturity and annual production of *Spartina* (plotted on a logarithmic scale) vs average height at maturity. The circles and the dashed line refer to standing crop, the points and solid line to production. The lines are least squares regressions for their respective points.

The results in Fig. 2 also indicated that the annual production of *Spartina* per square meter is correlated with the height of the plants at maturity. This relationship suggested that large-scale surveys of production in *Spartina* marshes could be accomplished merely by determining height-frequency distributions in the fall. Such a survey was made in September and October 1966. A grid with spacings equivalent to 5 km was placed over a map of the Beaufort area, and in each square containing salt marshes fronting on the Bogue Sound–Core Sound system a straight transect was run through a randomly selected point in the marshes (Fig. 1). Sampling consisted of measuring the height of two plants (to the nearest 5 cm) at 40-m intervals along the transect. To avoid sampling bias, which would have resulted from always starting measurements at the edge of the marsh, the initial measurement for each transect was made at some randomly selected distance up to 39 m from the edge.

The height-frequency distribution obtained from this survey (Fig. 3) showed that although some plants attain a height over 2 m, most of the grass was much shorter. Average height was 64 cm; plants 45 to 50 cm tall were most abundant.

In addition to measurements of height, one or more 0.2 m^2 samples of *Spartina* were collected near most of the transects. These 36 samples were analyzed like the previously collected 1 m^2 samples, and the results (Fig. 4) were used to relate standing crop and estimated production to average height. Height was more closely correlated with the logarithms of standing crop and production than with the untransformed values. Least squares regression equations were computed to relate standing crop at maturity and annual production (in grams dry weight per square meter) to average height at maturity (in centimeters):

$$\text{standing crop} = 158\ e^{0.0160\ \text{height}}$$

$$\text{production} = 214\ e^{0.0147\ \text{height}}$$

Averages for standing crop and annual production of *Spartina* per square meter for the entire marsh area were calculated by similar procedures from data in Figs. 3 and 4. The length-frequency distribution (Fig. 3) was divided into 25-cm intervals starting at 2.5 cm, and the percentage of the total observations contained in each interval was computed (Table 1). Mean height was also computed for each 25-cm interval. Using these mean heights, we estimated standing crop and annual production from the regression lines in Fig. 4 for each 25-cm interval (Table 1). These values were multiplied by percentages of the total observations represented by their respective intervals, summed and divided by 100 to obtain averages for the entire marsh. The averages, 545 g/m^2 standing crop and 650 g/m^2 annual production, are intermediate among those previously reported (Table 2). Comparison of values in Table 2 suggests that both production and standing crop of *Spartina* increase from north to south along the Atlantic Coast.

Table 1. Height, standing crop at maturity, and annual production of *Spartina*. Values for height are taken from 47 transects of salt marshes near Beaufort, N.C. Values for standing crop at maturity and annual production are taken from the regression lines in Fig. 4

Height Interval (cm)	Number of Observations	Percent of Observations	Average Height (cm)	Standing Crop (g/m^2)	Annual Production (g/m^2)
2.5–27.5	42	10.9	19.3	216	287
27.5–52.5	140	36.4	40.9	296	380
52.5–77.5	107	27.8	63.7	436	547
77.5–102.5	43	11.2	86.2	631	762
102.5–127.5	24	6.2	114.2	993	1148
127.5–152.5	15	3.9	140.0	1503	1671
152.5–177.5	10	2.6	163.5	2188	2344
177.5–202.5	2	0.5	185.0	3097	3236
202.5–227.5	1	0.25	220.0	5330	5410
227.5–252.5	1	0.25	230.0	6260	6270
Total	385	100.0			
Average for entire marsh			63.8	545	650

Table 2. Average standing crop at maturity and annual production of *Spartina alterniflora* marshes

Area	Standing Crop (g dry wt/m^2)	Annual Production (g dry wt/m^2)	Reference
New Jersey	268		Good 1965
Delaware	413	445	Morgan 1961
North Carolina	545	650	This study
Georgia	900	973	Standing crop, Teal 1962;[a] production, Smalley 1959

[a]Standing crop was estimated by assuming dry weight to be 40% of fresh weight.

Total Production and Importance of Spartina. Evaluating the potential importance of *Spartina* in estuarine food chains required measuring the total area of *Spartina* marshes adjoining the estuaries previously studied for phytoplankton production (Williams 1966). The extent of *Spartina* patches was observed from a low-flying aircraft and plotted on U.S. Geological Survey topographic charts. The total area of *Spartina* marshes, 25.5 km^2, multiplied by the average production, 650 g/m^2, yielded a total production of 16,600 metric tons dry weight. The average carbon content for 15 of the samples collected near the transects was 38.3% (0.95 confidence limits are 36.7% and 39.9%) of the dry weight. Production of the *Spartina* marshes therefore was *ca.* 6400 metric tons of carbon. *Spartina* production thus appears a significant part of the total plant production because in this inshore area annual phytoplankton net production in the adjoining 405 km^2 of open water was only 21,500 metric tons of carbon (Williams 1966).

Ash, Zinc, Manganese, and Iron in Spartina. Ash, zinc, manganese, and iron content were measured in sprouts, in mature plants, and in dead material from five of the samples taken in conjunction with the transects (Table 3). Samples were selected to represent the different types of *Spartina* marsh in the area studied. Variation among the five samples ranged from 1.6-fold for ash in sprouts to 9-fold for iron in dead material. Concentrations were generally higher in the samples from areas receiving freshwater drainage, A6 at the head of Newport River estuary and G5 near Oyster Creek, than in the remaining samples which were taken on Core Banks, an area with minimal runoff (Fig. 1).

The ash content of *Spartina* appeared to remain nearly constant during the life of the plant and to increase markedly after death. Our average values – 13% of dry weight for sprouts, 14% for mature plants, and 28% for dead material – were similar to values obtained previously by Burkholder (1956) and by de La Cruz (1965).

In every sample the concentrations of zinc, manganese, and iron were lowest in mature plants. Concentrations decreased between sprout stage and maturity, but after death increased to levels markedly above those present in sprouts. The initial decrease may have reflected dilution of actively growing tissues with structural material low in these metals. The increase in the concentration of these metals after death could not be caused alone by microbial decomposition of organic matter because the amount of increase was unrelated to that in total ash. It was also unlikely that increases in the metals and in ash could have resulted exclusively from penetration of sediment into interstices of the dead material. The concentrations of zinc, manganese, and iron in the silt-clay fraction of sediments from the Newport River estuary (Duke 1967) appeared less than those in the dead *Spartina*. Differences between our methods of sample preparation and those of Duke, however, precluded an unqualified dismissal of sediment infiltration as a factor increasing the trace metal content. Duke extracted his samples with 0.1 *N* HCl, which might not have dissolved as much of the metal as our prolonged refluxing with concentrated nitric acid. The increase in zinc, manganese, and iron in dead *Spartina* might represent materials deposited by its microflora, or might reflect some sorption process similar to that observed by Williams *et al.* (1960) in other dead plant materials.

The annual production of aboveground growth in a square kilometer of *Spartina* marsh utilized an average of 6 kg of zinc, 30 kg of manganese, and 400 kg of iron. The increase in trace metal content of this *Spartina* after death would use an additional 8 kg of zinc, 100 kg of manganese, and 2200 kg of iron. Compared with values in the literature for both terrestrial monocots (McIlrath 1964) and marine algae and submerged grasses (Angino *et al.* 1965, Black and Mitchell 1952, Parker 1962, Parker *et al.* 1963, Stevenson and Ufret 1966, Vinogradov 1953), the zinc content of *Spartina* was low; the manganese content, average; and the iron content, high. Correspondingly, our concentration factors for zinc with respect to seawater (Table 3) were low in comparison with those for other marine plants; for manganese, about average; and for iron, up to an order of magnitude above average (Polikarpov 1966).

The Role of Spartina in the Movement of Zinc, Manganese, and Iron. *Spartina* detritus may be important as a vehicle conveying radionuclides of iron into food chains in estuaries near Beaufort, N.C., and in other areas where *Spartina* provides a significant part of the total plant production.

Table 3. Composition of *Spartina alterniflora* and concentration factors with respect to seawater. Values for zinc, manganese, and iron in seawater used to compute the concentration factors are drawn from the literature. Zinc, 0.0097 mg/liter (Chipman *et al.* 1958); manganese, 0.0036 mg/liter (Fabricand *et al.* 1962); iron, 0.010 mg/liter (Goldberg 1963).

Sample Location	Dry Weight (% fresh wt)			Ash (% dry wt)			Zinc (ppm dry wt)			Manganese (ppm dry wt)			Iron (ppm dry wt)		
(Fig. 1)	Sprout	Mature	Dead	Sprout	Mature	Dead	Sprout	Mature	Dead	Sprout	Mature	Dead	Sprout	Mature	Dead
A6	25	28	21	16	20	29	20	12	37	105	95	330	4,800	2,600	10,500
E10	31	51	29	13	13	26	11	7	14	50	30	90	1,100	450	3,500
G5	34	38	27	12	15	20	14	11	29	130	50	420	1,900	650	4,600
I4	30	41	40	10	7	29	19	7	22	50	45	160	1,400	320	8,000
J3	60	46	55	14	17	38	14	10	16	75	45	160	700	300	2,250
Geometric average	34	40	33	13	14	28	15	9	22	76	49	200	1,600	590	5,000
Concentration factors[a] with respect to seawater							530	370	750	7200	5400	18,000	54,000	24,000	164,000

[a]Concentration factors are on a wet weight basis.

Spartina is consumed mostly as detritus, and the already high iron content of the living plant is markedly increased after death. The long period required for growth permits considerable decay of short-lived radioisotopes, like ^{59}Fe (half-life, 45 days), taken up during growth. Loss due to radioactive decay is, however, negated by the uptake of additional amounts of iron after death. The high iron content of dead *Spartina* may also elevate the iron content of organisms feeding on it (Stevenson and Ufret 1966) and thus increase the transport of iron radioisotopes into the animal community. *Spartina* is less likely to have as much importance in the transport of zinc and manganese, because concentrations of these elements in *Spartina* are not particularly high in comparison with other marine plants. Isotopes of both zinc and manganese would nonetheless be presented to detrital-feeding organisms at levels considerably greater than those occurring in the water, and certain organisms might still selectively concentrate these elements from *Spartina* detritus.

The results of this study suggest that further research is needed on the role of *Spartina* in the cycling of radioisotopes. A full evaluation of its actual role will be difficult since the problems involved are complex and largely unexplored. Information is minimal on the chemistry and microbiology of *Spartina* decay, on the importance of *Spartina* detritus in the diet of specific animals, and on the availability of materials in *Spartina* detritus to animal consumers. In view of the importance ascribed to *Spartina* in the food web in estuaries (Odum 1961) the investigation of these problems seems desirable.

Acknowledgments

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